

Development of a High Performance, Low-Profile Translation Table with Wire Feedthrough

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Abstract

NEAScout, a 6U cubesat, will use an 85 m² solar sail to travel to a near-earth asteroid for observation. Over the course of the 3-year mission, a combination of reaction wheels, cold gas reaction control system, and a slow rotisserie roll about the solar sail's normal axis were expected to handle attitude control and adjust for imperfections in the deployed sail. As the design for NEAScout matured, one of the critical design parameters, the offset in the center of mass and center of pressure (CP/CM offset), proved to be sub-optimal. After significant mission and control analysis, the CP/CM offset was addressed and a new subsystem was introduced to NEAScout. This system, called the Active Mass Translator (AMT), would reside near the geometric center of NEAScout and adjust the CM by moving one portion of the flight system relative to the other. The AMT was given limited design space—about 17 mm of the vehicle's assembly height—and was required to generate ± 10 cm by ± 5 cm translation to sub-millimeter accuracy. Furthermore, the design must accommodate a large wire bundle of small gage, single strand wire and coax cables fed through the center of the mechanism. The bend radius, bend resistance, and the exposure to deep space environment complicates the AMT design and operation and necessitated a unique design to mitigate risks of wire bundle damage, binding, and cold-welding during operation. This paper will outline the design constraints for the AMT, discuss the methods and reasoning for design, and identify the lessons learned through the design downselect process and breadboarding for designing low-profile translation stages with feedthrough capabilities.

Executive Summary

The primary source of design complexity was the requirements placed on the AMT at the onset of developmental activities. No requirement was simple to satisfy. The translation table was required to generate ± 10 cm by ± 5 cm (in the X and Y directions, respectively) given a volumetric profile of 22.6 x 10.0 x 1.7 cm. Although the motion was relatively large in comparison to the design space, the AMT was also required to have sub-millimeter precision—both in translation and knowledge. Furthermore, the system had to weigh less than 250 grams; this included control boards, thermal controls, and secondary structure. Finally, the AMT was required to have a locking feature. The locking mechanism would secure the 2 halves of NEAScout in the ground, launch and deployment stages of the mission. Therefore, the locking feature was treated as primary structure due to the load requirements of integration, launch and deployment. Shown below is a prototype AMT and a wire bundle simulator. This prototype demonstrated the potential to satisfy the translation requirement, but would fail to meet requirements for the feedthrough wires, locking mechanism, and mass.

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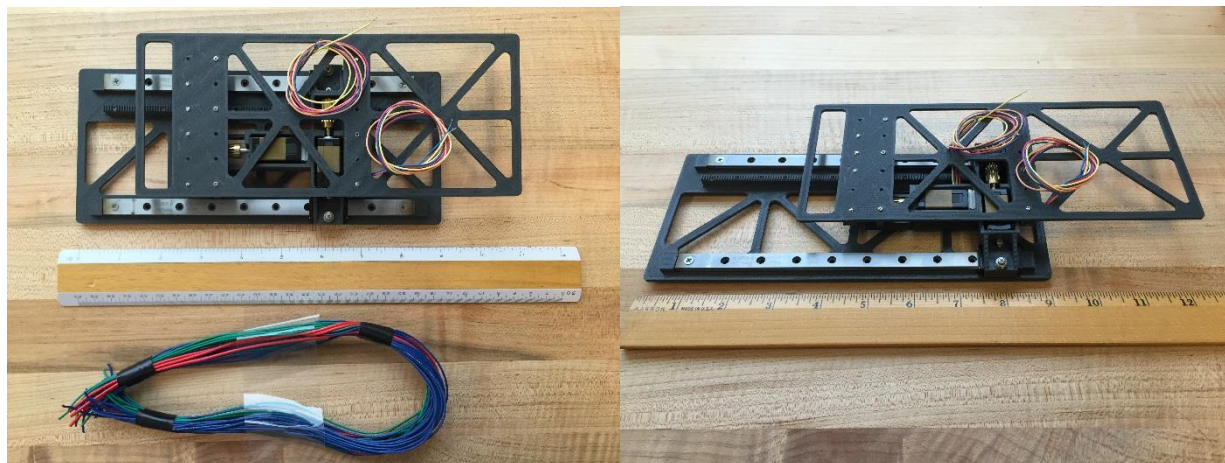


Figure 1. AMT Prototype and Wire Bundle Simulator.

As the AMT design matured, it was determined that the requirements with greatest impact to mission success were those related to the feedthrough wires, locking mechanism, and range of motion. A previous AMS paper by Sheah Pimak, “Lessons Learned to Avoid Coax Cable Failure in Moving Mechanical Mechanisms” noted significant failures of coax cables due to cold welding in moving assemblies. This research when combined with the required 3-year life span of the AMT illuminated a clear issue that would require much investigation, innovation and testing. Test plans have been formed to include mock wire bundles and simulate life cycle motion to determine failure modes; expected life span of the wires depending on gage, bundle design, and location; and bend resistance. Results from these tests will provide insight into the design of the wire bundle, connector locations, and the location of the rails and linear systems.

The next concern, the locking mechanism, is expected to be a simpler design hurdle, though no less important. The large translation field and thin vertical profile disallowed conventional locking features such as clevises, ramps, or pin pullers. After researching for commercial items with minimal shock, FOD, and power draws, TiNi’s Frangibolts were selected for evaluation. The robust Frangibolt design showed positive margins of safety during preliminary analysis, which gave the design team confidence in their applicability, even in launch environments. However, integration into the AMT will be difficult. Despite the small volume, optimal locations of the Frangibolts impede the motion of the AMT. Testing plans have been written to determine the best locations for the vendor-supplied locking features. These tests will place the Frangibolts and mass simulators in random vibration environments then actuate to release the two simulators and allow motion for the AMT. The locking mechanism tests will be the longest, as each test would require new bolts, reassembly, and individual random vibe tests.

The final mission-critical requirement, the translation performance, will create the most design and test intensive processes. As mentioned earlier, the field of operation spanned a 20 x 10 cm rectangle—a space only 25 cm² smaller than the design space—and this motion was required to be accurate to 0.25 mm. Undoubtedly, there exist linear systems that could produce the motion to this length and accuracy, however after considerable investigation, many systems had to be discarded due to mass and volume limitations, leaving only micro ball screws and threaded rod and nut assemblies in the design trade space. Tests have also been planned for both systems to determine torque margins. These margins will account for the stepper motor size, gear ratio, thread size, thread pitch and nut type. With so many variables to

test for, the test requires significant control and attention to external factors such as temperature and cleanliness. A 3D printed test fixture will be designed and built for motor, thread and nut interchanging. The data gathered will include torque margins, positional accuracy, and wear. The results from the tests will determine the best linear system and motor, which in turn will drive the minimum height of the AMT and the performance requirements on NEAScout's control systems. Shown below is a model of the AMT prior to testing.

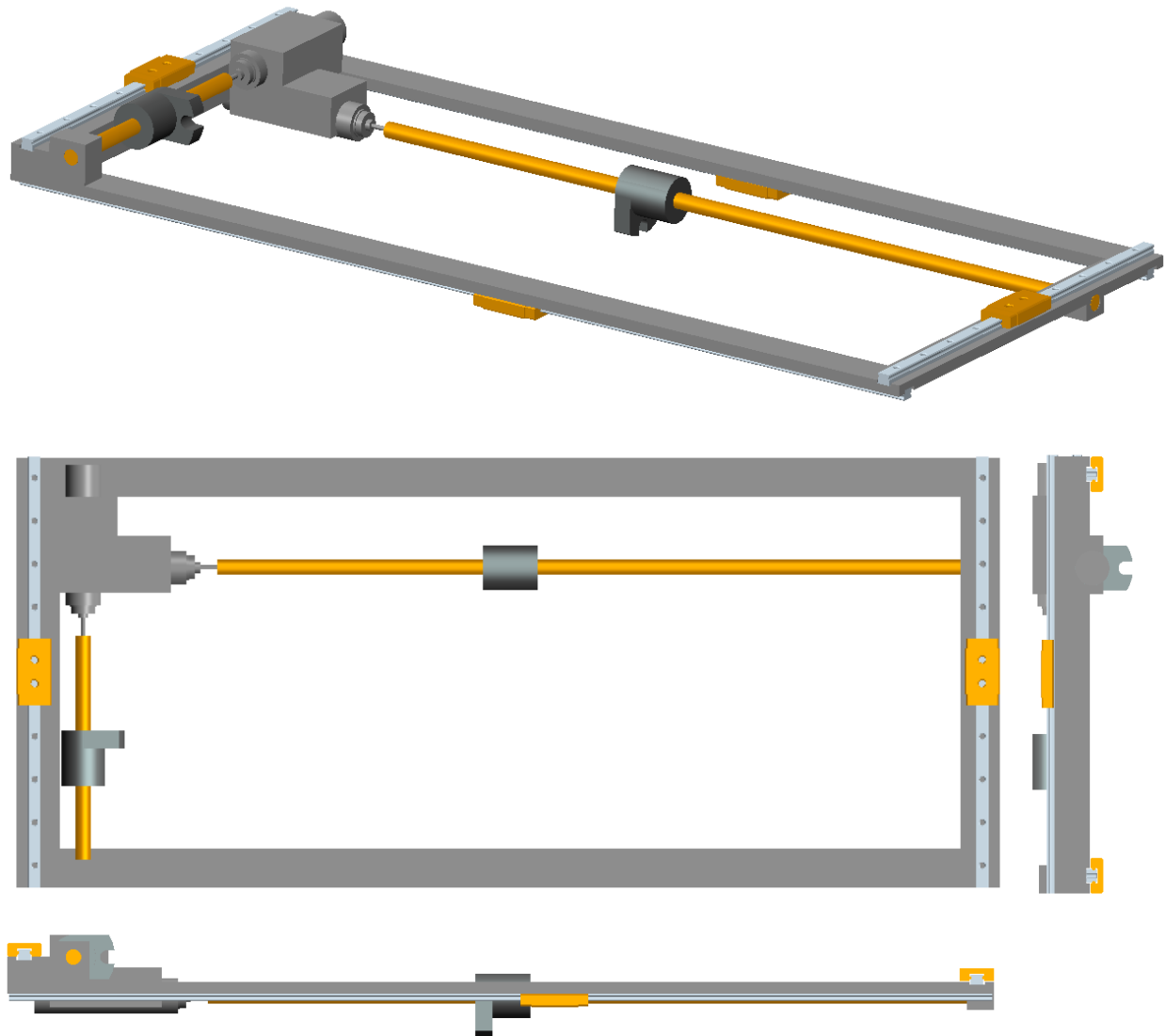


Figure 2. AMT Design Pre-Test Phase.

Clearly, there is much to learn from the NEAScout AMT design and tests, and we are confident that many more lessons need be learned following manufacturing and integration. Although this system is still early in design, the fast paced schedule and nearing deadlines require prototype manufacturing and testing procedures be completed by the end of 2015. The design team expects to complete the 3 tests described above and will collect extensive data related to the translation performance, locking mechanism, and wire bundle design. These testing activities are not only critical to the success of the AMT and NEAScout, but

also to engineers and designers who will encounter similar hurdles when developing systems similar to the AMT. Shown below is the testing schedule for the AMT.

Testing Activity	Data to Collect	Start Date	End Date
Locking Mechanism	Translation distance Accuracy Torque Margins	11/9/2015	11/13/2015
Wire Bundle Design	Life Span Bundle Location Wire/Connector Arrangement	11/16/2015	11/20/2015
Translation Performance	Mechanism Location Stability Safety Factors and Margins	11/23/2015	12/4/2015

Figure 3. AMT Test Schedule.

The Active Mass Translator aboard NASA's NEAScout is unique in mechanical design. The testing procedures, though not inherently unique in process, are distinctive in their application to a system with such extreme design limitations. Results from the testing will show where designers should place their attention at the onset of design activities for translation stages when limited by mass and volume. The value added by the AMT is the design and testing procedures aiming to produce novel a design solution for the mass, volume and wire feedthrough requirements. These exercises, when carried out in a thorough and careful manner, will allow future designers of similar systems to avoid many of the design hurdles, redesigns and omissions carried out by the AMT design team at MSFC.